MULTI-AGENCY RADIATION SURVEY AND SITE INVESTIGATION MANUAL, REVISION 1, CORRECTIONS

Corrections were made to the MARSSIM, Revision 1, which was published on October 18, 2000 (65 Federal Register 62531). The pages affected by these modifications are listed below and are contained within this file. A complete list of corrections and will be available in the 2001 Federal Register Notice on the MARSSIM web site at: http://www.epa.gov/radiation/marssim/

Directions for holders of the August 2000 Final Revision 1 MARSSIM

Replace the following August 2000 pages with the modified June 2001 pages:

v, xi, xii, xv, xxiii, xxviii, Roadmap-8, 4-24, 5-12, 6-16, 6-30, 6-37, 8-19, 8-23, C-19

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ABBREVIATIONS

AEA	Atomic Energy Act
AEC	Atomic Energy Commission
AFI	Air Force Instructions
ALARA	as low as reasonably achievable
AMC	Army Material Command
ANSI	American National Standards Institute
AR	Army Regulations
ARA	Army Radiation Authorization
ASTM	American Society of Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
CAA	Clean Air Act
Capt.	Captain (Air Force)
CAPT	Captain (Navy)
CDR	Commander
CEDE	committed effective dose equivalent
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CFR	Code of Federal Regulations
CHP	Certified Health Physicist
CPM	counts per minute
DCF	dose conversion factor
DCGL	derived concentration guideline level
$DCGL_{EMC}$	DCGL for small areas of elevated activity, used with the EMC
$DCGL_W$	DCGL for average concentrations over a wide area, used with statistical tests
DEFT	Decision Error Feasibility Trials
DLC	Data Life Cycle
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DQA	Data Quality Assessment
DQO	Data Quality Objectives
EERF	Eastern Environmental Radiation Facility
Ehf	human factors efficiency
EMC	elevated measurement comparison
EML	Environmental Measurements Laboratory
EMMI	Environmental Monitoring Methods Index
EPA	Environmental Protection Agency
EPIC	Environmental Photographic Interpretation Center
ERAMS	Environmental Radiation Ambient Monitoring System

ERRATA AND ADDENDA

In response to comments received on the December 1997 Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), minor modifications were made to individual pages. Modifications to the manual that correct errors are listed as errata, while modifications made to clarify guidance or provide additional information are referred to as addenda. The pages affected by these modifications are listed here and have the date of the modification in the footer. A complete list of comments and resolutions is available on the MARSSIM web site at:

http://www.epa.gov/radiation/marssim/

August 2000

Pages Modified to Correct Errata

v, xv, xxvii, Roadmap-4, 1-3, 2-6, 2-11, 2-12, 4-33, 4-35, 4-36, 4-37, 4-38, 5-33, 6-4, 6-10, 6-23, 6-37, 7-20, 8-19, 9-3, 9-4, 9-7, Ref-3, Ref-4, A-2, A-5, A-7, A-11, A-14, A-19, E-2, H-7, H-8, H-10, H-12, H-14, H-16, H-32, I-30, N-2, N-6, N-8, N-11, N-13

Pages Modified to Provide Addenda

xiii, xxiii, xxviii, 5-30, 5-34, 7-8, C-20, C-21, D-23, I-5, L-2, L-3, L-4, L-5, L-8, M-10

June 2001

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v, xi, xii, xv, xxiii, xxviii, Roadmap-8, 4-24, 5-12, 6-16, 6-30, 6-37, 8-19, C-19

Pages Modified to Provide Addenda

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The next step, after determining whether or not the contaminant is present in background, is to estimate the variability of the contaminant concentration, σ. The standard deviation of the contaminant concentration determined from the preliminary survey results should provide an appropriate estimate of σ. If the contaminant is present in background, the variability in the survey unit (σ_s) and the variability in the reference area (σ_r) should both be estimated. The larger of the two values should be selected for determining the number of data points. Underestimating σ can underestimate the number of measurements needed to demonstrate compliance with the regulation, which increases the probability the survey unit will fail the statistical test. Overestimating σ can result in collecting more data than is necessary to demonstrate compliance.

☞	It is better to overestimate values of σ_s and σ_r.

☞	When σ_s and σ_r are different, select the larger of the two values.

The third step is to calculate the relative shift, Δ/σ. The variability of the contaminant concentration, σ, was determined in the previous step. The shift, Δ, is equal to the width of the gray region. The upper bound of the gray region is defined as the $DCGL_W$. The lower bound of the gray region (LBGR) is a site-specific parameter, adjusted to provide a value for Δ/σ between one and three. Δ/σ can be adjusted using the following steps:

- Initially select LBGR to equal one half the $DCGL_W$. This means $\Delta = (DCGL_W - LBGR)$ also equals one half the $DCGL_W$. Calculate Δ/σ.
- If Δ/σ is between one and three, obtain the appropriate number of data points from Table 5.3 or Table 5.5.
- If Δ/σ is less than one, select a lower value for LBGR. Continue to select lower values for LBGR until Δ/σ is greater than or equal to one, or until LBGR equals zero.
- If Δ/σ is greater than three, select a higher value for LBGR. Continue to select higher values for LBGR until Δ/σ is less than or equal to three.

Alternatively, Δ/σ can be adjusted by solving the following equation and calculating Δ/σ:

$$LBGR = DCGL_W - \sigma$$

If LBGR is less than zero, Δ/σ can be calculated as $DCGL_W/\sigma$.

☞	Adjust the LBGR to provide a value for Δ/σ between one and three.

contamination. Window ledges and outside exits (doors, doorways, landings, stairways, *etc.*) are also building exterior surfaces that should be addressed.

4.8.3.2 Land Areas

Depending upon site processes and operating history, the radiological survey may include varying portions of the land areas. Potentially contaminated open land or paved areas to be considered include storage areas (*e.g.*, equipment, product, waste, and raw material), liquid waste collection lagoons and sumps, areas downwind (based on predominant wind directions on an average annual basis, if possible) of stack release points, and surface drainage pathways. Additionally, roadways and railways that may have been used for transport of radioactive or contaminated materials that may not have been adequately contained could also be potentially contaminated.

Buried piping, underground tanks, sewers, spill areas, and septic leach fields that may have received contaminated liquids are locations of possible contamination that may necessitate sampling of subsurface soil (Section 7.5.3). Information regarding soil type (*e.g.*, clay, sand) may provide insight into the retention or migration characteristics of specific radionuclides. The need for special sampling by coring or split-spoon equipment should be anticipated for characterization surveys.

If radioactive waste has been removed, surveys of excavated areas will be necessary before backfilling. If the waste is to be left in place, subsurface sampling around the burial site perimeter to assess the potential for future migration may be necessary.

Additionally, potentially contaminated rivers, harbors, shorelines, and other outdoor areas may require survey activities including environmental media (*e.g.*, sediment, marine biota) associated with these areas.

4.8.4 Clearing to Provide Access

In addition to the physical characteristics of the site, a major consideration is how to address inaccessible areas that have a potential for residual radioactivity. Inaccessible areas may need significant effort and resources to adequately survey. This section provides a description of common inaccessible areas that may have to be considered. The level of effort expended to access these difficult-to-reach areas should be commensurate with the potential for residual activity. For example, the potential for the presence of residual activity behind walls should be established before significant effort is expended to remove drywall.

5.3.3.3 Other Measurements/Sampling Locations

Surface Water and Sediments. Surface water and sediment sampling may be necessary depending on the potential for these media to be contaminated. The contamination potential depends on several factors, including the proximity of surface water bodies to the site, size of the drainage area, total annual rainfall, and spatial and temporal variability in surface water flow rate and volume. Refer to Section 3.6.3.3 for further consideration of the necessity for surface water and sediment sampling.

Characterizing surface water involves techniques that determine the extent and distribution of contaminants. This may be performed by collecting grab samples of the surface water in a well-mixed zone. At certain sites, it may be necessary to collect stratified water samples to provide information on the vertical distribution of contamination. Sediment sampling should also be performed to assess the relationship between the composition of the suspended sediment and the bedload sediment fractions (*i.e.*, suspended sediments compared to deposited sediments). When judgment sampling is used to find radionuclides in sediments, contaminated sediments are more likely to be accumulated on fine-grained deposits found in low-energy environments (*e.g.*, deposited silt on inner curves of streams).

Radionuclide concentrations in background water samples should be determined for a sufficient number of water samples that are upstream of the site or in areas unaffected by site operations. Consideration should be given to any spatial or temporal variations in the background radionuclide concentrations.

Sampling locations should be documented using reference system coordinates, if appropriate, or scale drawings of the surface water bodies. Effects of variability of surface water flow rate should be considered. Surface scans for gamma activity may be conducted in areas likely to contain residual activity (*e.g.*, along the banks) based on the results of the document review and/or preliminary investigation surveys.

Surface water sampling should be performed in areas of runoff from active operations, at plant outfall locations, both upstream and downstream of the outfall, and any other areas likely to contain residual activity (see Section 3.6.3.3). Measurements of radionuclide concentrations in water should include gross alpha and gross beta assessments, as well as any necessary radionuclide-specific analyses. Non-radiological parameters, such as specific conductance, pH, and total organic carbon may be used as surrogate indicators of potential contamination, provided that a specific relationship exists between the radionuclide concentration and the level of the indicator (*e.g.*, a linear relationship between pH and the radionuclide concentration in water is found to exist, then the pH may be measured such that the radionuclide concentration can be calculated based on the known relationship rather than performing an expensive nuclide-specific analysis). The use of surrogate measurements is discussed in Section 4.3.2.

6.5.1.1 Gas-Filled Detectors

Radiation interacts with the fill gas, producing ion-pairs that are collected by charged electrodes. Commonly used gas-filled detectors are categorized as ionization, proportional, or Geiger-Mueller (GM), referring to the region of gas amplification in which they are operated. The fill gas varies, but the most common are: 1) air, 2) argon with a small amount of organic methane (usually 10% methane by mass, referred to as P-10 gas), and 3) argon or helium with a small amount of a halogen such as chlorine or bromine added as a quenching agent.

6.5.1.2 Scintillation Detectors

Radiation interacts with a solid or liquid medium causing electronic transitions to excited states in a luminescent material. The excited states decay rapidly, emitting photons that in turn are captured by a photomultiplier tube. The ensuing electrical signal is proportional to the scintillator light output, which, under the right conditions, is proportional to the energy loss that produced the scintillation. The most common scintillant materials are NaI(Tl), ZnS(Ag), Cd(Te), and CsI(Tl) which are used in traditional radiation survey instruments such as the NaI(Tl) detector used for gamma surveys and the ZnS(Ag) detector for alpha surveys.

6.5.1.3 Solid-State Detectors

Radiation interacting with a semiconductor material creates electron-hole pairs that are collected by a charged electrode. The design and operating conditions of a specific solid-state detector determines the types of radiations (alpha, beta, and/or gamma) that can be measured, the detection level of the measurements, and the ability of the detector to resolve the energies of the interacting radiations. The semiconductor materials currently being used are germanium and silicon which are available in both n and p types in various configurations.

Spectrometric techniques using these detectors provide a marked increase in sensitivity in many situations. When a particular radionuclide contributes only a fraction of the total particle fluence or photon fluence, or both, from all sources (natural or manmade background), gross measurements are inadequate and nuclide-specific measurements are necessary. Spectrometry provides the means to discriminate among various radionuclides on the basis of characteristic energies. *In-situ* gamma spectrometry is particularly effective in field measurements since the penetrating nature of the radiation allows one to “see” beyond immediate surface contamination. The availability of large, high efficiency germanium detectors permits measurement of low abundance gamma emitters such as ^{238}U as well as low energy emitters such as ^{241}Am and ^{239}Pu.

where

C_s	=	integrated counts recorded by the instrument
T_s	=	time period over which the counts were recorded in seconds
ε_T	=	total efficiency of the instrument in counts per disintegration, effectively the product of the instrument efficiency (ε_i) and the source efficiency (ε_s)
A	=	physical probe area in m^2

To convert instrument counts to conventional surface activity units, Equation 6-1 can be modified as shown in Equation 6-2.

$$\frac{dpm}{100\ cm^2} = \frac{\frac{C_s}{T_s}}{(\varepsilon_T) \times (A/100)} \qquad (6\text{-}2)$$

where T_s is recorded in minutes instead of seconds, and A is recorded in cm^2 instead of m^2.

Some instruments have background counts associated with the operation of the instrument. A correction for instrument background can be included in the data conversion calculation as shown in Equation 6-3. Note that the instrument background is not the same as the measurements in the background reference area used to perform the statistical tests described in Chapter 8.

$$Bq/m^2 = \frac{\frac{C_s}{T_s} - \frac{C_b}{T_b}}{(\varepsilon_T \times A)} \qquad (6\text{-}3)$$

where

C_b	=	background counts recorded by the instrument
T_b	=	time period over which the background counts were recorded in seconds

Equation 6-3 can be modified to provide conventional surface activity units as shown in Equation 6-4.

$$\frac{dpm}{100\ cm^2} = \frac{\frac{C_s}{T_s} - \frac{C_b}{T_b}}{(\varepsilon_T) \times (A/100)} \qquad (6\text{-}4)$$

B = 40 counts
C = (5 dpm/count)(Bq/60 dpm)(1/15 cm^2 probe area)(10,000 cm^2/m^2)
= 55.6 Bq/m^2-counts

The MDC is calculated using Equation 6-7:

$$MDC = 55.6 \times (3 + 4.65\sqrt{40}) = 1{,}800\ Bq/m^2\ (1{,}100\ dpm/100\ cm^2)$$

The critical level, L_c, for this example is calculated from Equation 6-6:

$$L_C = 2.33\sqrt{B} = 15 \text{ counts}$$

Given the above scenario, if a person asked what level of contamination could be detected 95% of the time using this method, the answer would be 1,800 Bq/m^2 (1,100 dpm/100 cm^2). When actually performing measurements using this method, any count yielding greater than 55 total counts, or greater than 15 net counts (55-40=15) during a period of one minute, would be regarded as greater than background.

6.7.2 Scanning Sensitivity

The ability to identify a small area of elevated radioactivity during surface scanning is dependent upon the surveyor's skill in recognizing an increase in the audible or display output of an instrument. For notation purposes, the term "scanning sensitivity" is used throughout this section to describe the ability of a surveyor to detect a pre-determined level of contamination with a detector. The greater the sensitivity, the lower the level of contamination that can be detected.

Many of the radiological instruments and monitoring techniques typically used for occupational health physics activities may not provide the detection sensitivities necessary to demonstrate compliance with the DCGLs. The detection sensitivity for a given application can be improved (*i.e.*, lower the MDC) by: 1) selecting an instrument with a higher detection efficiency or a lower background, 2) decreasing the scanning speed, or 3) increasing the size of the effective probe area without significantly increasing the background response.

Scanning is usually performed during radiological surveys in support of decommissioning to identify the presence of any areas of elevated activity. The probability of detecting residual contamination in the field depends not only on the sensitivity of the survey instrumentation when used in the scanning mode of operation, but is also affected by the surveyor's ability—*i.e.*, human factors. The surveyor must make a decision whether the signals represent only the

8.4.3 Wilcoxon Rank Sum Test Example: Class 2 Interior Drywall Survey Unit

In this example, the gas-flow proportional counter measures total beta-gamma activity (see Appendix H) and the measurements are not radionuclide specific. The two-sample nonparametric test is appropriate for the Class 2 interior drywall survey unit because gross beta-gamma activity contributes to background even though the radionuclide of interest does not appear in background.

Table 8.3 shows that the DQOs for this survey unit include $\alpha = 0.025$ and $\beta = 0.05$. The $DCGL_W$ is 8,300 Bq/m^2 (5,000 dpm per 100 cm^2) and the estimated standard deviation of the measurements is about $\sigma = 1,040$ Bq/m^2 (625 dpm per 100 cm^2). The estimated standard deviation is 8 times less than the $DCGL_W$. With this level of precision, the width of the gray region can be made fairly narrow. As noted earlier, sample sizes do not decrease very much once Δ/σ exceeds 3 or 4. In this example, the lower bound for the gray region was set so that Δ/σ is about 4.

If $\quad \Delta/\sigma = (DCGL_W - LBGR)/\sigma$
$= 4$

then $\quad LBGR = DCGL_W - 4\sigma$
$= 8,300 - (4 \times 1,040)$
$= 4,100$ Bq/m^2 (2,500 dpm per 100 cm^2).

In Table 5.3, one finds that the number of measurements estimated for the WRS test is 11 in each survey unit and 11 in each reference area ($\alpha = 0.025$, $\beta = 0.05$, and $\Delta/\sigma = 4$). (Table I.2b in Appendix I also lists the number of measurements estimated for the WRS test.) This survey unit was classified as Class 2, so the 11 measurements needed in the survey unit and the 11 measurements needed in the reference area were made using a random-start triangular grid.[4]

Table 8.6 lists the data obtained from the gas-flow proportional counter in units of counts per minute. A reading of 160 cpm with this instrument corresponds to the $DCGL_W$ of 8,300 Bq/m^2 (5,000 dpm per 100 cm^2). Column A lists the measurement results as they were obtained. The average and standard deviation of the reference area measurements are 44 and 4.4 cpm, respectively. The average and standard deviation of the survey unit measurements are 98 and 5.3 cpm, respectively.

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[4] A random start systematic grid is used in Class 2 and 3 survey units primarily to limit the size of any potential elevated areas. Since areas of elevated activity are not an issue in the reference areas, the measurement locations can be either random or on a random start systematic grid (see Section 5.5.2.5).

8.5.2 Interpretation of Statistical Test Results

The result of the statistical test is the decision to reject or not to reject the null hypothesis. Provided that the results of investigations triggered by the EMC were resolved, a rejection of the null hypothesis leads to the decision that the survey unit meets the release criterion. However, estimating the average residual radioactivity in the survey unit may also be necessary so that dose or risk calculations can be made. This estimate is designated δ. The average concentration is generally the best estimator for δ (EPA 1992g). However, only the unbiased measurements from the statistically designed survey should be used in the calculation of δ.

If residual radioactivity is found in an isolated area of elevated activity—in addition to residual radioactivity distributed relatively uniformly across the survey unit—the unity rule (Section 4.3.3) can be used to ensure that the total dose is within the release criterion:

$$\frac{\delta}{DCGL_W} + \frac{(average\ concentration\ in\ elevated\ area\ -\ \delta)}{(area\ factor\ for\ elevated\ area)(DCGL_W)} < 1 \qquad \textbf{8-2}$$

If there is more than one elevated area, a separate term should be included for each. When calculating δ for use in this inequality, measurements falling within the elevated area may be excluded providing the overall average in the survey unit is less than the $DCGL_W$. As an alternative to the unity rule, the dose or risk due to the actual residual radioactivity distribution can be calculated if there is an appropriate exposure pathway model available. Note that these considerations generally apply only to Class 1 survey units, since areas of elevated activity should not exist in Class 2 or Class 3 survey units.

A retrospective power analysis for the test will often be useful, especially when the null hypothesis is not rejected (see Appendix I.9). When the null hypothesis is not rejected, it may be because it is in fact true, or it may be because the test did not have sufficient power to detect that it is not true. The power of the test will be primarily affected by changes in the actual number of measurements obtained and their standard deviation. An effective survey design will slightly overestimate both the number of measurements and the standard deviation to ensure adequate power. This insures that a survey unit is not subjected to additional remediation simply because the final status survey is not sensitive enough to detect that residual radioactivity is below the guideline level. When the null hypothesis is rejected, the power of the test becomes a somewhat moot question. Nonetheless, even in this case, a retrospective power curve can be a useful diagnostic tool and an aid to designing future surveys.

8.5.3 If the Survey Unit Fails

The guidance provided in MARSSIM is fairly explicit concerning the steps that should be taken to show that a survey unit meets release criteria. Less has been said about the procedures that should be used if at any point the survey unit fails. This is primarily because there are many different ways that a survey unit may fail the final status survey. The overall level of residual

Examples of Army Regulations (ARs):

1. AR 11-9, The Army Radiation Safety Program
2. AR 40-5, Preventive Medicine.
3. AR 40-10, Health Hazard Assessment Program in Support of the Army Materiel Acquisition Decision Process.
4. AR 200-1, Environmental Protection and Enhancement.
5. AR 200-2, Environmental Effects of Army Actions.
6. AR 385-30, Safety Color Code Markings and Signs.
7. AR 700-64, Radioactive Commodities in the DOD Supply System.
8. AR 750-25, Army Test, Measurement, and Diagnostic Equipment (TMDE) Calibration and Repair Support Program.
9. TB MED 521, Management and Control of Diagnostic X-Ray, Therapeutic X-Ray, and Gamma Beam Equipment.
10. TB MED 522, Control of Health Hazards from Protective Material Used in Self-Luminous Devices.
11. TB MED 525, Control of Hazards to Health from Ionizing Radiation Used by the Army Medical Department.
12. TB 43-180, Calibration and Repair Requirements for the Maintenance of Army Materiel.
13. TB 43-0108, Handling, Storage, and Disposal of Army Aircraft Components Containing Radioactive Material.
14. TB 43-0116, Identification of Radioactive Items in the Army.
15. TB 43-0122, Identification of U.S. Army Communications-Electronic Command Managed Radioactive items in the Army.
16. TB 43-0141, Safe Handling, Maintenance, Storage, and Disposal of Radioactive Commodities Managed by U.S. Army Troop Support and Aviation Material Readiness Command (Including Aircraft Components).
17. TB 43-0197, Instructions for Safe Handling, Maintenance, Storage, and Disposal of Radioactive Items Managed by U.S. Army Armament Material Command.
18. TB 43-0216, Safety and Hazard Warnings for Operation and Maintenance of TACOM Equipment.
19. TM 3-261, Handling and Disposal of Unwanted Radioactive Material.
20. TM 55-315, Transportability Guidance for Safe Transport of Radioactive Materials.

Examples of Navy Regulations:

1. NAVMED P-5055, Radiation Health Protection Manual.
2. NAVSEA SO420-AA-RAD-010, Radiological Affairs Support Program (RASP) Manual.
3. OPNAV 6470.3, Navy Radiation Safety Committee.
4. NAVSEA 5100.18A, Radiological Affairs Support Program.
5. OPNAV 5100.8G, Navy Safety and Occupational Safety and Health Program.